XXXIX. The Effect of Absolute Brightness Upon Color Contrast

By Ruth L. Crane

Kirschmann[1] laid down the law that "simultaneous color-contrast is best when brightness-contrast is eliminated or reduced to a minimum."[2] This relationship, as Kirschmann pointed out, is implicit in Schmerler's earlier study.[3] Schmerler gives a table which shows that a "strong" contrast-effect occurs under conditions in which the brightness of the colored inducing field and of the grey field which undergoes induction are approximately equal; whereas the contrast-effect is "weak" when the one field is very much lighter or darker than the other.[4] Kirschmann tabulates the actual values of the brightnesses of gray disks (in degrees of Bk and W) which gave the "maximal value of contrast" with certain colored inducing fields.[5] His data are few, but the indication is that the relationship holds without regard to the saturation of the inducing field; fields of the same brightness but of different saturations induce maximal contrast upon fields of the same brightness, although the *amount* of the maximal effect does, naturally, depend on saturation. Neither Schmerler nor Kirschmann gives figures to show the manner in which the contrast-effect decreases when the contrasting field is made lighter or darker than the inducing field. Obviously, if we were to measure the contrast-effect of a constant inducing field, we could plot the amount of contrast-effect for varying brightnesses of a gray field, and could determine the nature of a function, in which the maximum would occur at the brightness of the inducing field. The form of this function constitutes a psychological problem.

Pretori and Sachs[6] measured the contrast-effect of a colored background upon a gray ring by determining how much of the color, complementary to the contrast-color, must be introduced into the ring in order just barely to neutralize the contrast-color. The results, on their face value, appear to contradict Kirschmann's law; hence we shall do well to examine them critically.

Both background and ring were made of rotating colored disks.[7] There were four experiments; in every one the background consisted of a color and black and white, and the ring of the same color (less of it, to kill the contrast) and black and white. The color-valence (C. V.) of a combination is measured directly by the number of degrees of color. The white-valence (W. V.) is measured by the number of degrees of white *plus* the white-equivalent of the black (in this case about 1.7% of the number of degrees of Bk) *plus* the white-equiv-

[1] A. Kirschmann, *Philos. Stud.*, 6, 1891, 417-491.

[2] Pp. 475, 491.

[3] B. Schmerler, *ibid.*, I, 1883, 379-416; esp. 387ff.

[4] *Cf.* Schmerler, 388 (Table), and Kirschmann, 475.

[5] P. 476.

[6] H. Pretori and M. Sachs, *Pflüger's Arch.*, 60, 1895, 71-90. This paper is summarized, a little obscurely, by J. H. Parsons, *Introducton to the Study of Colour Vision*, 1915, 264-266. (A confusing misstatement occurs p. 265, l. 28.)

[7] *Cf.* also L. J. Martin, *Am. J. Psychol.*, 24, 1913, 33f., who does not, however, mention Pretori and Sachs.

alent of the color (about 25% in the case of red). The value of the W. V. is a direct measure of the brightness of the color. The ratio of the C. V. to the W. V. is a measure of the "saturation" of the color. (These relationships are Hering's.) The results may be summarized as follows.

Exp.	Background			Ring		
	C.V.	W.V.= Brightness	$\frac{\text{C.V.}}{\text{W.V.}}$ = Saturation	C.V.	W.V.= Brightness	$\frac{\text{C.V.}}{\text{W.V.}}$ = Saturation
I	constant	constant	constant	increased (proportionally)	increased	constant
II-1	increased	constant	increased	constant	decreased	increased (proport. to incr. in bckgr.)
II-2	constant	increased	decreased	constant	increased	decreased (proport. to decr. in bckgr.)
II-3	increased (proportionally)	increased	constant	constant	constant	constant

In Exp. I the background was kept constant. The C. V. of the ring was increased arbitrarily; then the W. V. was increased until the contrast-color of the ring was just eliminated. The necessary increase of W. V. was about proportional to the increase of C. V.; hence the saturation remained constant. In Exp. II 1, the C. V. of the background was increased arbitrarily and the W. V. was kept constant; hence the saturation of the background increased. The C. V. of the ring was kept constant and the W. V. decreased until the contrast-color was eliminated. The resulting increase in saturation of the ring was approximately proportional to the increase of saturation of the background. In Exp. II 2, the C. V. of the background was kept constant and the W. V. was increased; hence the saturation was decreased. The C. V. of the ring was kept constant and the W. V. increased until the contrast-effect was just about to appear. The decrease in saturation proved to be very nearly proportional to the decrease in saturation of the background. Finally, in Exp. II 3, the saturation of the background was kept constant by increasing the C. V. and W. V. in a constant proportion. Under these circumstances the contrast-effect in the ring was eliminated without any considerable change in the ring.

These results appear to show that the amount of color-contrast is dependent upon the saturation of the inducing field and is independent of the relative brightnesses of the fields. A contrast-effect produced

by a constant saturation is neutralized by a constant saturation, even though the brightness of the ring be increased while the background remains constant (I) or the brightness of the background be increased while the ring remains constant (II 3). The contrast-effect of an increasing saturation is neutralized by a saturation which continues in the same proportion to it, even though the ring be continuously darkened with respect to the background (II 1). Does Kirschmann's law break down under these conditions?

The generalizations of the table are, however, only approximate; and the actual deviations show a trend that is in accordance with Kirschmann's finding. In all of Pretori and Sachs' cases the ring is darker than the background, and generally very much darker. Thus, in Exp. I, when the ring is brightened, it approaches the background in tint and should tend to have more color induced in it; the actual saturation necessary for the elimination of the contrast-color should therefore increase gradually. If we examine the data (pp. 79f.), we find that the saturations of the ring do increase somewhat, just as Kirschmann's law would have led us to expect. The courses of the saturations of the ring in the two cases are:

0.7, 0.9, 1.2, 1.3, 1.3, 1.3, 1.3;
and 0.4, 0.7, 0.9, 1.1, 1.2, 1.3, 1.3, 1.4, 1.4.

In Exp. II 1, the ring begins as darker than the background and is made still darker; a constant saturation of background should continuously induce less color. Thus we should expect, under Kirschmann's law, that the actual increase in saturation of the background would require something less than a proportional increase in saturation of the ring. And we find our expectation justified in the averages of the two cases (pp. 82f.):

When the background changes as	1.00	:	1.25	:	1.50,
the ring changes as	1.00	:	1.07	:	1.17;
and when the background changes as	1.00	:	1.50	:	2.00,
the ring changes as	1.00	:	1.30	:	1.50.

In Exp. II 2 the background and ring grow lighter together; hence we might expect proportionality between the saturation of background and ring. The actual data (p. 85) show a much closer proportionality than occurs in any other case.

When background changes as	1.00	:	0.75	:	0.50,
the ring changes as	1.00	:	0.77	:	0.57.

Finally, with the increase of brightness-contrast due to the lightening background of Exp. II 3, we should expect the necessary saturation of the ring to decrease slightly. The actual average decreases (pp. 87f.) are as 1.00 : 0.95 : 0.92 and as 1.00 : 0.90 : 0.87 : 0.92.

Pretori and Sachs thus substantiate Kirschmann indirectly and even furnish a hint of the form of the function[8] when the induced field is darker than the inducing.

Ebbinghaus[9] notes that approximately equal brightnesses of the contrasting field are necessary for maximal contrast. He explains the decreased contrast-effect on grays lighter than the inducing color by the desaturating effect of light gray (*cf.* Hering's relation of W. V. to saturation, above); and the decreased effect on dark grays

[8]The deviations in Exp. I are consistent with the data that we shall present later.

[9]H. Ebbinghaus, *Grundzüge der Psychologie,* I, 1905, 239.

as due to irradiation. Since different factors are operative at the two extremes, one might expect the function to be asymmetrical.

Recently Cook and Kunkel[10] have published data in which "the law of greatest color contrast when brightness contrast is eliminated seems to hold . . . only to a certain extent. It is apparently partially counteracted by another tendency, namely, for the lighter rings to suffer greater contrast effect than the darker ones. . . . The two laws. . . . sometimes work together and sometimes cut across each other." The authors are far from dogmatic about this second law or tendency; they suggest further experiments, and phrase the problem: "Do lighter surfaces suffer more color contrast effect than darker ones, under equal conditions of brightness contrast between the contrast-inducing and contrast-suffering surfaces?"

It is not obvious upon what aspect of their data Cook and Kunkel base this suggestion. They may mean that a given color tends to induce more color upon a lighter gray, or else that a lighter color tends to induce more color upon a gray of the same tint. In the first case, this second tendency would operate to make the function that occurs under Kirschmann's law asymmetrical. When rings darker than their backgrounds are lightened the two tendencies would be additive; when lighter rings are made still lighter the tendencies would be in opposition; and whether the function rose or fell would depend on the dominant tendency. If the tendency of Kirschmann's law were the more effectual, then the function would simply slope off more gradually for the light rings than it rose for the dark; if the tendency for lighter rings to suffer more contrast-effect were dominant, then the function might continue to rise for the lighter rings, though less rapidly than for the darker. In the second case, we should find the function symmetrical with respect to the tint of the inducing ground, but greater amounts of induced color would occur for the lighter grounds.

Cook and Kunkel's data provide some evidence for the first conclusion. Of their 18 cases (p. 19), 5 show a continuous increase in the amount of induced color when the brightness of the ring is increased, 6 show an increase followed by a decrease, and 7 are equivocal. When all the results are averaged, the tendency is toward continuous increase. Every function is, however, based upon four points only, and the differences are small; hence, as the authors themselves point out, we must accept general conclusions with reserve.

The alternate conclusion, namely, that lighter colors induce, upon grays of the same brightness, more contrast-color, seems, at first glance, to be established. Hering Y, for example, is over six times as bright (by the flicker method) as Hering R and induces over five times as many degrees of BG. The correlation between the average amounts of induced color (3 O's) and the flicker-brightnesses of inducing backgrounds is about 79%. We could not presumably expect a higher value when the saturations are uncontrolled. Hering Y is probably of poorer saturation than Hering R and loses on that account.

Cook and Kunkel measured amount of contrast by the total degrees of color necessary on the second color-mixer to match the induced color of the ring. The amount of colored paper in a color-combination, however, by no means measures the amount of color *seen*. White paper has a much greater desaturating effect than black.

[10] H. D. Cook and F. M. Kunkel, *Psychol. Rev. Monog.*, No. 96, 1916, 1-39; esp. 18f. 22, 39.

Hence 180°R + 180°Bk looks much redder than 180°R + 180° W, although the angular amount of R is the same. In Hering's terms—as we saw in our discussion of Pretori and Sachs—the amount of colored paper is one thing, the "color-valence;" the amount of color is another thing, the "saturation", and is the quotient of the C. V. by the W. V. (brightness). Cook and Kunkel deal with color-valences; Kirschmann was interested in the amount of color seen (*i. e.,* the saturation, if we grant the hypothesis that equal saturations, defined as above, appear equally colored). Cook and Kunkel do not give the data which permit the computation of the W. V.'s of their mixtures and hence of the saturations. The general indication of their data is that the increased contrast (C. V.) in both the cases we have discussed is roughly proportional to the increase in brightness (W. V.) upon which it depends; that is to say, the saturation (granting that Hering's relation holds approximately) does *not* tend to increase with lighter rings. In the first case, we may argue that the contrast-color (saturation) suffers as much from brightness-contrast in rings lighter than the inducing ground as it does in darker rings, but that more colored stimulus (C. V.) is required to produce a given amount of color (saturation) in the lighter rings. In the second case, we may urge that all colors of the same degree of saturation induce equal amounts of contrast-color in grays of the same brightness as the inducing color, but that lighter grays, which match the lighter colors in tint, require more C. V. in order that they shall appear equally colored.

Experimental

We have repeated Cook and Kunkel's experiment with various tints of a single color, with the intention of gaining more light on the proposed second law. The work was done in the Cornell Summer Session, 1917. There was time only for a single determination of every point; hence the work can be regarded as little more than preliminary.

We used three observers: Miss M. Cowdrick (*C*), Mr. H. D. Williams (*W*), and Dr. E. G. Boring (*B*).

We followed Titchener's general procedure[11], but made the ring by using three sizes of disks[12]. We sécured constant illumination by working in a dark-room with artificial daylight[13]. A single "day-lite" unit (200-watt Mazda Type-C lamp) was placed 70 cm. in front of the color mixers and slightly above them. The observer was seated 2 m. from the mixers and looked under the lamp. He could not see the light directly. The size of the disks and the distance between the two motors duplicated the dimensions of Cook and Kunkel (p. 12). A large gray exposure-screen, which obscured both disks and background, controlled the time of exposure. The disks were never seen except when in rotation. In the early stages of making a match the observer was allowed long exposures. He was compelled, however, to make his final judgment of equality with a brief exposure of approximately 1 sec.[14]

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[11] E. B. Titchener, *Experimental Psychology,* I, i, 1901, 16, 19.

[12] Pretori and Sachs; Martin; *cf.* note 7 above.

[13] *Cf.* A. J. Brown Some Uses of Artificial Daylight in the Psychological Laboratory, *Am. J. of Psychol.,* 27, 1916, 427-429.

[14] A precaution which Cook and Kunkel did not observe, although they tried fixation. *V.* pp. 11, 20f.; also the fourth conclusion, p. 39. On adaptation, *cf.* Titchener, *op. cit.,* I, ii, 33.

Ideally we should have selected as inducing backgrounds three reds of equal chroma and very different tints. We lacked time, however, to carry through a psychological method for the equation of the chromas; and we feared to trust that equal saturations, according to the Hering formula, would give subjectively equal chromas. Instead we selected a standard R of middle tint (S); two much lighter R's, approximately equal in tint (actually of equal W. V.), one slightly better and the other slightly poorer in chroma than S; and two darker R's of equal tint, one slightly better and the other slightly poorer than S. Later we added another pair of still lighter R's and another pair of still darker R's. We checked the subjective equality of tint and the just noticeable subjective difference of chroma by the consensus of our three observers. We used Hering R, baryta W, and velvet Bk papers. We determined the tint of the R by the method of constant stimuli (100 series, 5 stimulus pairs): 48W + 312Bk. (A flicker-photometer result is 57W + 303Bk.) Velvet Bk, under our conditions, had a light value of about .05 baryta W (Kirschmann photometer). From these values we could compute the W.V. and hence the saturation of every combination. The background for the matches were arranged in accordance with the W. V. of the inducing colors. In the description of the following nine inducing colors, D means much darker; d, darker; S, standard; l, lighter; L, much lighter; g, slightly better chroma than S; p, slightly poorer chroma than S; C. V., color-valence; W. V., white-valence; saturation, C. V./W. V.

		C.V.	W.V.	Saturation
1. Dp:	60R + 2W + 298Bk.....	60	27	2.22
2. Dg:	70R + 285Bk.....	70	27	2.78
3. dp:	130R + 15W + 215Bk.....	130	49	2.65
4. dg:	150R + 12W + 198Bk.....	150	49	3.06
5. S:	180R + 24W + 156Bk.....	180	64	2.82
6. lp:	250R + 33W + 77Bk.....	250	82	3.05
7. lg.	270R + 30W + 60Bk.....	270	82	3.29
8. Lp:	300R + 47W + 13Bk.....	300	102	2.94
9. Lg:	315R + 45W	315	102	3.09

All nine colors were used with *W* and *C*. *B* worked with S and the extreme pairs only.

With every inducing color we began with a ring of 18°W and, after matching the contrast-color of the ring by the disks on the second mixer, increased the W in the ring by 30°; and so on, by 30° steps, until in two successive matches the observer required no color on the second motor.

The contrast-color of the ring was matched by baryta W, velvet Bk, Hering B, and Hering G. The C. V.'s were taken as the sum of the degrees of G + B. As the proportion of G to B was fairly constant, no great error was involved.[15] In computing the W. V. of the match of every ring we had to rely on flicker-photometer equations for B and G: G = 148 W + 212 Bk; B = 33 W + 327 Bk. Since our data are rough, any error involved in this method of photometry is probably not serious. The saturations of the induced contrast-color in every ring were computed from these values of C. V. and W. V.

[15] The av. ratios of G to B and their M. V.'s, where 10° or more of color were used, are: for *W*, 1.27 ± .15; for *C*, 1.16 ± .30; for B, 1.26 ± .18. Cook and Kunkel added degrees of G and B; p. 18.

The C. V.'s are shown in Table I; the saturations in Table II. The tendency in both cases is for the values to start, with the darkest ring, at a minimum, rise to a maximum, and then drop off to zero with the lighter rings. Hering R is a dark paper; hence we were unable to get a range of darker rings as great as the range of lighter rings. Our darkest ring (18° W + 342° Bk; W. V. = 35) was actually lighter than our darkest colors (Dg, Dp; W. V. = 27). If we had foreseen this difficulty we could have used a ring of 360° Bk (W. V. = 18) or possibly a lightless hole (W. V. = 0); but even these stimuli would not have given symmetry.[16]

TABLE I

COLOR-VALENCES

Obs.	Degrees of W in contr. ring	Inducing Colors								
		Dp	Dg	dp	dg	S	lp	lg	Lp	Lg
	18	20	19	0	8	6	0	8	0	0
	48	0	7	22	23	26	24	28	15	15
	78	0	0	7	7	15	31	22	24	21
	108		0	0	3	0	15	18	22	34
W	138			0	0	0	8	0	20	33
	168				0		0	0	20	13
	198						0		0	3
	228								0	0
	258									0
	18	5	9	7	9	5	5	10	5	0
	48	5	4	16	12	19	22	17	19	15
	78	0	0	7	6	14	22	15	34	32
	108	0	0	0	3	11	19	14	35	35
C	138			0	0	14	7	15	7	15
	168			0	0	11	0	13	0	5
	198					22	0	13	0	0
	228					0		9		0
	258							0		
	18	15	11			28			0	15
	48	10	9			49			23	33
	78	0	3			44			46	55
	108	0	0			25			61	46
B	138		0			33			64	63
	168					0			47	44
	198					0			0	21
	228								0	0
	258									0

[16]One can not overcome the difficulty by partial light-adaptation; such a procedure would give darker R's as well as darker Bk's. The only solution seems to be a lighter colored paper, say Hering G or Y.

TABLE II
Saturations

Obs.	Degrees of W in contr. ring	Inducing Colors								
		Dp	Dg	dp	dg	S	lp	lg	Lp	Lg
	18	.39	.37	0	.23	.23	0	.19	0	0
	48	0	.10	.30	.30	.36	.39	.45	.24	.22
	78	0	0	.07	.07	.16	.34	.37	.26	.23
	108		0	0	.02	0	.14	.15	.20	.30
W	138			0	0	0	.06	0	.13	.23
	168				0		0	0	.10	.08
	198						0		0	.01
	228								0	0
	258									0
	18	.11	.19	.17	.22	.14	.14	.26	.15	0
	48	.07	.05	.21	.17	.26	.33	.27	.32	.24
	78	0	0	.08	.07	.15	.26	.18	.38	.34
	108	0	0	0	.02	.09	.20	.12	.34	.30
C	138			0	0	.10	.05	.12	.05	.12
	168			0	0	.06	0	.09	0	.03
	198					.10	0	.07	0	0
	228					0		.04		0
	258							0		
	18	.33	.24			.64			0	.47
	48	.14	.12			.65			.35	.51
	78	0	.03			.42			.56	.60
	108	0	0			.21			.58	.46
B	138		0			.21			.46	.46
	168					0			.28	.29
	198					0			0	.12
	228								0	0
	258									0

TABLE III
Maximal Color-Valences and Saturations Induced by Different Inducing Colors

Inducing Color	Dp	Dg	dp	dg	S	lp	lg	Lp	Lg
W.V.	27	27	49	49	64	82	82	102	102
Saturation	2.22	2.78	2.65	3.06	2.82	3.05	3.29	2.94	3.09
Maximal C.V. Observed:									
W	20	19	22	23	26	31	28	24	34
C	5	9	16	12	22	22	17	35	35
B	15	11			49			64	63

TABLE III—*Continued*

Maximal C.V. Computed:									
W..............	15	18	16	17	25	27	25	27	29
C..............	6	9	16	10	16	24	16	31	29
B..............	16	12			43			61	58
Maximal Saturation Observed:									
W..............	.39	.37	.30	.30	.36	.39	.45	.26	.30
C..............	.11	.19	.21	.22	.26	.33	.27	.38	.34
B..............	.33	.24			.65			.58	.60

Table III shows the maximal amounts of induction occurring for every inducing color. The observed maximal C. V.'s from Table I are first tabulated. In some cases, however, the data of Table I do not indicate clearly the amount of the maximum; the function is irregular, and we wished that all points might be brought to bear upon the amount and position of the maximum. Accordingly we smoothed out the curves by calculating, by the method of least squares, the most probable parabola; and in this way determined the computed maximal C. V.'s of Table III.[17] Finally, Table III gives the observed maximal saturations. These values are indicated unequivocally in Table II; hence it was not necessary to generalize the curve in accordance with an hypothesis.[18]

Table III shows that the maximal C. V.'s tend in general to increase with the brightness (W. V.) of the inducing color. The computed values, which are based on three to nine points instead of a single one, show this tendency more strikingly. Cook and Kunkel's law appears to hold with the C. V.'s. With the saturations, however, it does not hold. It is true that there is evident with the saturations some slight tendency for increase, but this tendency appears to be due to the differences in saturation of the inducing colors. The darker colors unfortunately turned out to be the less saturated. The correlations between the saturations of the inducing colors and the maximal induced saturations run about 60 to 70%.[19]

[17]The details of the computation can not be given here. We used the parabola, $y = Ax^2 + Bx + C$, because a preliminary investigation showed that it approximately fitted the average of the data if the extreme points were omitted. The normal equations are:

$$\begin{aligned}
[x^4]\,A + [x^3]\,B + [x^2]\,C &= [x^2y] \\
[x^3]\,A + [x^2]\,B + [x]\,C &= [xy] \\
[x^2]\,A + [x]\,B + nC &= [y]
\end{aligned}$$

Then the brightness of the ring suffering maximal contrast is $x_m = -B/2A$. The required maximal ordinate is $y_m = C - Ax_m^2$. The data for Dp and Dg do not show a maximum; hence for them we used the parabola, $y = Ax^2 + C$, where x_m is assumed 0, and $y_m = C$.

[18]If a parabola be passed through the three maximal points (*cf.* F. M. Urban, *Statistical Methods,* 1908, 124f.), the maximal values are not altered within our rough limits of precision.

[19]For *W* the correlation, r, = 10.2%; for *C*, r = 76.0%; for *B*, r = 59.6%. But if for *W* the two rather unreliable values for Dp and Dg be discarded, then his r = 61.8%.

Hence we may conclude that such significant variation of the saturations as exists is due to the saturation of the inducing colors and not to their tint.

Table IV gives the tints (W. V.'s) of the gray rings in which the maximal C. V.'s and saturations were induced. The points for the C. V.'s were found by the parabolic interpolation mentioned above. The points of maximal saturation were computed by an interpolation in which the bell-shaped curve of error was used as an hypothesis.[20] There are some wide deviations, but in general the tints undergoing maximal induction increase with the tints of the inducing colors, thus establishing approximately the principle of Kirschmann's law. The data for the saturations accord with the law about twice as well as the data for the C. V.'s.[21]

TABLE IV

WHITE-VALENCES (TINTS) OF THE GRAY RINGS IN WHICH THE MAXIMAL COLOR-VALENCES AND SATURATIONS WERE INDUCED BY THE DIFFERENT INDUCING COLORS

Inducing Color	Dp	Dg	dp	dg	S	lp	lg	Lp	Lg
W.V.	27	27	49	49	64	82	82	102	102
W.V. of Maximal C.V. (computed):									
W	< 35	< 35	75	68	73	88	83	125	119
C	35±	< 35	64	55	122	92	124	101	110
B	< 35	< 35			84			125	128
W.V. of Maximal Saturation (computed):									
W	< 35	< 35	64	56	63	65	72	86	108
C	< 35	< 35	57	35	61	74	38	82	91
B	< 35	< 35			48			114	90

Finally we note, in so far as our scanty data permit us, that there is no evidence of asymmetry of function about the point of maximal induction. If we arrange all our data with the maxima coincident (omitting Dp and Dg) and average the coincident values, we get for the C. V.'s an average function:

2, 7, 16, 27, 27, 16, 5, 1, 0;

and for the saturations an average function:

.19, .26, .36, .25, .13, .06, .02, .01.

We may conclude then:

(1) That light colors exhibit no marked tendency to induce more saturated contrast-colors than do dark colors;

[20] Both the C. V.-function and the saturation-function tend to be bell-shaped. We adjusted the saturations to the curve of error by omitting all zeros and assuming the maximum of the curve to be the observed maximum. We could not, therefore, use the curve of error with the C. V.'s, because with them we wished also to determine the amount of the maximum. The curve of error is, however, the more representative hypothesis and is the easier to apply. The normal equations are similar to those of the method of constant stimuli.

[21] When agreement is measured by the square root of the sums of the squares of the deviations.

(2) That light colors do induce contrast-colors of a greater color-valence, but that this greater color-valence is approximately proportional to the greater color-valence which, in relation to their saturation, the light inducing colors themselves possess;

(3) That maximal saturations are induced in grays of approximately the same brightness as the inducing color (Kirschmann's law), and that the induced saturation falls off to zero in an approximately symmetrical function with increased brightness-contrast in either direction;

(4) That, less accurately stated, maximal color-valences are induced in grays of approximately the same brightness as the inducing color;

(5) That equal saturations, determined as the quotient of color-valence by white-valence, are at least approximately equivalent to subjectively equal chromas, and may be used in a rough way to indicate equal chromas; and

(6) That rough functions, such as we have determined, can be made to yield more general results, if they are taken as wholes by adjustment, by the method of least squares, to some general hypothesis.

Ebbinghaus' explanation of Kirschmann's law, namely, that the fading out of color in the light grays is due to the desaturating effect of the white and the fading out in the dark grays to irradiation, does not appear, on these conclusions, to be valid. Ebbinghaus would lead one to expect that with the light gray rings the color-valence would remain about constant, the white-valence would increase, and the saturation would consequently decrease, eventually, no doubt, to a subliminal value. But we have seen that the color-valence falls off quite as rapidly as the white-valence increases. Furthermore, Ebbinghaus' supposition that different causes are operative at the two extremes of brightness-contrast would make an asymmetrical function probable; whereas our data indicate, though but roughly, that the function is symmetrical.